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16. ABSTRACT

A study was conducted using a nuclear gage to evaluate the compaction capabilities of static steel and pneumatic and vibratory rollers for asphalt concrete pavements. The performance of these rollers was also compared using the results of permeability tests and determinations of apparent migration of fine aggregate and asphalt toward the surface of the asphalt concrete. Method No. Calif. 913, "Method For Evaluating the Compaction Capabilities of Asphalt Concrete Compactors", was developed. When tested in accordance with this test method, it was found that several vibratory rollers were satisfactory. However, several other vibratory rollers tested did not comply due to an inability to provide 1) 95 percent relative compaction and/or 2) a smooth pavement surface free of ridges, indentations, or other objectionable features. It was determined that compatible combinations of amplitude, frequency, and roller weight must be provided for satisfactory compaction to be achieved.

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RONALD REAGAN, Governor

DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
TRANSPORTATION LABORATORY
5900 FOLSOM BLVD., SACRAMENTO 95819

July 1973

Interim Report No. 3
CA-DOT-TL-3294-3-73-19
FHWA No. D-05-26

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

VIBRATORY COMPACTION OF ASPHALT CONCRETE PAVEMENTS

George B. Sherman
Principal Investigator

James A. Cechetini
Co-Principal Investigator

James A. Cechetini
Analysis and Report

Very truly yours,

JOHN L. BEATON
Director, Transportation Laboratory

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ACKNOWLEDGMENTS

The authors wish to express their appreciation to the Construction personnel of the various Highway Districts of the State of California for their cooperation in obtaining the data for this investigation.

This is the third interim report of a research project to study the compaction of asphalt concrete pavement. This work was performed in cooperation with the U. S. Department of Transportation Federal Highway Administration as Item D-05-26 of Federal Program No. HPR-1(5)

INTRODUCTION

The first rollers used for compacting asphalt concrete pavements were static, steel tired rollers utilizing their overall weight to produce a consolidated layer. These rollers are still in use today. A second phase of compaction was entered with the advent of the pneumatic roller. These rollers were used initially to "tighten" the surface of the pavement. "Air-on-the run" allowed variable pressures to be applied to the pavement and the pneumatic roller was used by many as a breakdown roller. Although experimentation with static steel and pneumatic rollers is still going on, both are now widely accepted in the U.S.A. The use of vibratory rollers, however, is relatively new in the U.S.A. and acceptance is now limited primarily to those states using method specifications.

During the early part of this research program on asphalt concrete compaction, a study was conducted on compaction of thick lift asphalt concrete pavements and an interim report published in 1968[1]. It was found that the use of an eight-ton vibratory roller resulted in generally higher densities and lower permeabilities than those obtained using static steel and pneumatic rolling sequences. Questions have since been raised regarding the effectiveness of vibratory rollers on asphalt concrete pavements placed in lifts 0.2-0.3 ft. thick. This study was, therefore, initiated to acquire more data on the effectiveness of vibratory rollers and to determine if their use should be allowed on State contracts.

Several vibratory rollers were subsequently studied on projects located throughout California. The effect of the rollers on permeability, migration of the asphalt and/or aggregate fines to the surface, and density was determined. A method of testing and qualifying compaction equipment was developed and has since been adopted.

CONCLUSIONS

The following conclusions were reached regarding vibratory rollers tested as per the requirements of Method No. Calif. 913 (See Appendix A).

1. There are several models of vibratory rollers that can meet the California Division of Highways' 95 percent relative compaction requirement for asphalt concrete pavements.

2. Use of vibratory rollers produced lower asphalt concrete permeabilities than those obtained using pneumatic rollers, either partially or exclusively.

3. Vibratory rollers may cause slight migration of asphalt and/or asphalt coated fines to the surface.

4. There is no single combination of frequency, amplitude, and weight for all vibratory rollers that will ensure maximum pavement compaction.

5. Vibratory rollers that operate at frequencies lower than 1700 VPM will leave undulations, giving the surface a "washboard" appearance.

6. Pavement surface undulations will not result if vibratory rollers are operated at a frequency above 1800 VPM.

7. The double vibratory drum rollers tested to date have provided higher asphalt concrete densities with fewer coverages than all the other types of compactors tested.

8. Vibratory rollers using pneumatic drive wheels were not satisfactory due to "pick-up" and/or final appearance of the pavement.

IMPLEMENTATION

From the findings of this study, a qualification procedure, Method No. Calif. 913, was developed to evaluate compaction equipment. Standard Special Provisions (Appendix B) have been written that allow the use of vibratory rollers (or any other type) on California Division of Highways' projects provided they can qualify as per Method No. Calif. 913 (See Appendix A).

VIBRATORY ROLLER EVALUATION

For good compaction to be achieved, a firm, stable base must be provided beneath the material to be compacted. All the test sections met this requirement regardless of the base composition.

Perhaps the single most important factor influencing compactability is the temperature of the mix during the rolling operation[1]. For this reason, a temperature of 270° F to 280° F was required at the mid depth of the asphalt concrete lift being placed at the time breakdown rolling was started on all the test sections used for this study. This temperature requirement has been incorporated in Method No. Calif. 913.

Other factors that may influence the degree to which adequate compaction can be achieved are aggregate size and shape, gradation, and asphalt type and content. Hard, rounded aggregate, especially in the coarse sizes, does not provide enough internal friction or interlock to adequately distribute the load immediately beneath the roller. Pushing and shoving or checking of the mix will usually occur. This can also be caused by a gradation having insufficient fines (minus No. 200) and/or an excessive amount of material retained on the Nos. 20 to 40 U.S. standard sieve sizes. In addition, asphalts from certain areas in California have caused difficulty during the rolling operation. These asphalts are slow setting and, during the rolling sequence, the mix moves excessively, causing check marks in the pavement surface.

To analyze each of these factors, as well as the roller, was beyond the scope of this study. However, by selecting projects carefully and controlling some of the variables such as temperature, lift thickness and type of mix, the effect of the roller was isolated fairly well.

The test method used for evaluating the various types of compactors has been adopted as Method No. Calif. 913 (Appendix A). Briefly, this test procedure consists of selecting a 300 foot test section one lane wide which will become an integral part of the highway under construction. This site should be on a tangent and as near level as possible. One-minute nuclear gauge density readings are taken using the backscatter mode after each successive coverage until 95 percent relative compaction is reached or until no appreciable increase in density is obtained by additional rolling. This relative compaction is defined as the ratio of the in place density of the asphalt concrete pavement to the test maximum density (average of five specimens) of the same asphalt concrete mix when compacted using the California kneading compactor, Test Method No. Calif. 304. Thirty density measurements are then made at randomly selected locations throughout the 300 foot test section (10 within each of three 100 foot test sections). These test locations are selected using random numbers. For compactor acceptance, the minimum mean relative compaction for each 100 foot test section must be 95 percent, and none of the individual tests can be below 92 percent. Other reasons for rejection include ridges, indentations, or other objectionable marks on the asphalt concrete after final rolling has been completed.

As stated in Method No. Calif. 913, the compacted thickness of the asphalt concrete test mat must be between 0.2' and 0.3'. The reasons for this thickness requirement are: (a) previous studies have shown that if a roller can achieve a relative compaction of 95 percent for this thickness, no difficulties will be encountered obtaining 95 percent relative compaction on thicker lifts[1], and (b) the compacted lift thickness of the majority of the asphalt concrete pavements constructed in California are within these limits even though thicker lifts are allowed.

Those vibratory rollers which have met our relative compaction, as well as other requirements, are discussed below.

<u>Essick VR-54-RE</u> (Figure 1)

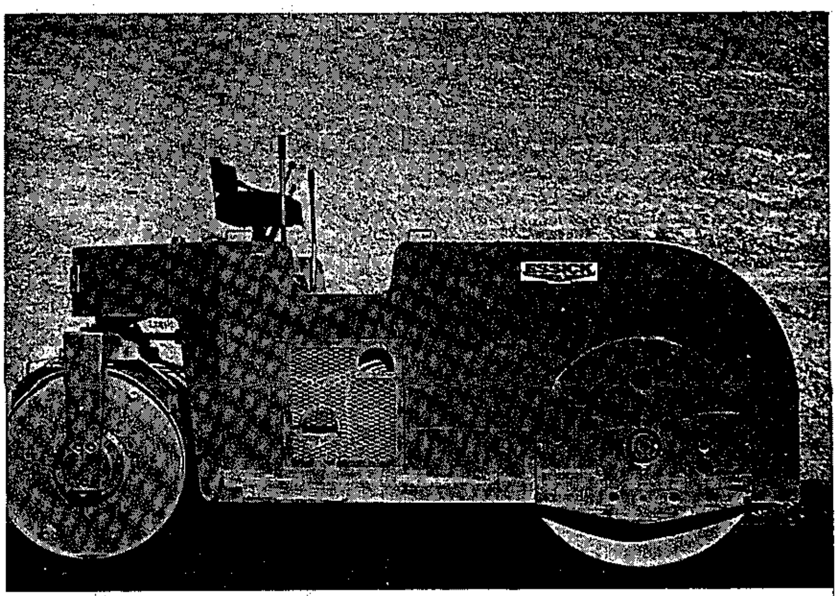


Figure 1 - Essick VR-54-RE

The unballasted weight of this double steel drum roller is 7.0 tons. With ballast, this can be increased to 8.5 tons. For our study, the weight was 8.0 tons. Only the drive drum vibrates. It is 51" in diameter and 54" in width. A hydrostatic drive produces a frequency of 3000 VPM and an amplitude of .030". The vibratory unit on this roller can be shut off, permitting the roller to be used as a finishing roller. The overall length of this roller is 13' 10".

This vibratory roller has been used to compact seven test sections throughout California. A typical density growth curve is shown in Figure 2. Generally, maximum density is obtained after 6 coverages. This vibratory roller never failed to attain 95 percent relative compaction on any of the test sections.

The VR-54-RE has had minor problems with "pickup" on the drive drum; this was primarily due to the water spray system. This was corrected by the manufacturer by changing the water system from gravity flow to a pressure system, replacing all the nozzles, and coating the insides of the water tanks to eliminate rust scale.

<u>Bomag - B.W. 200</u> (Figure 3)

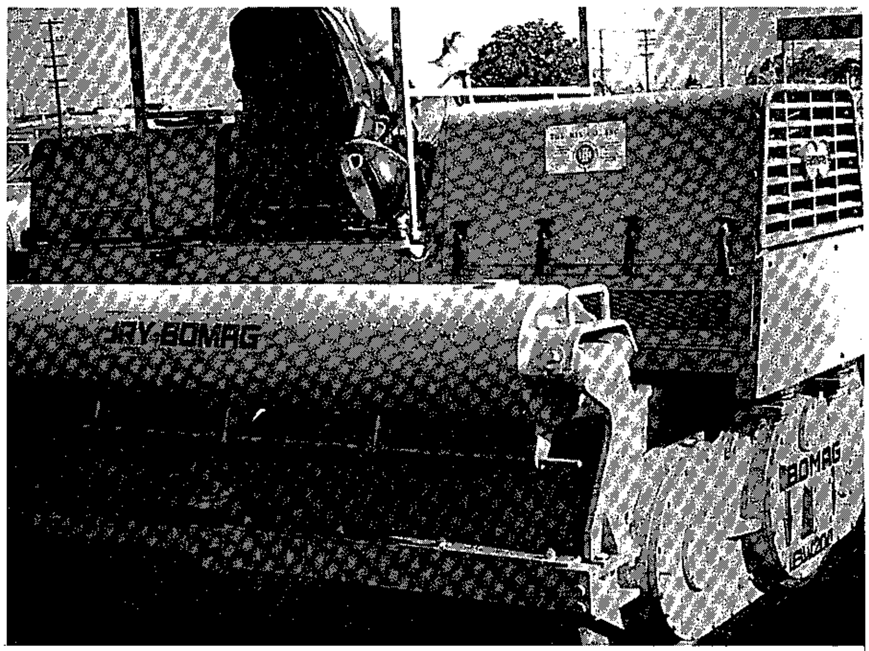
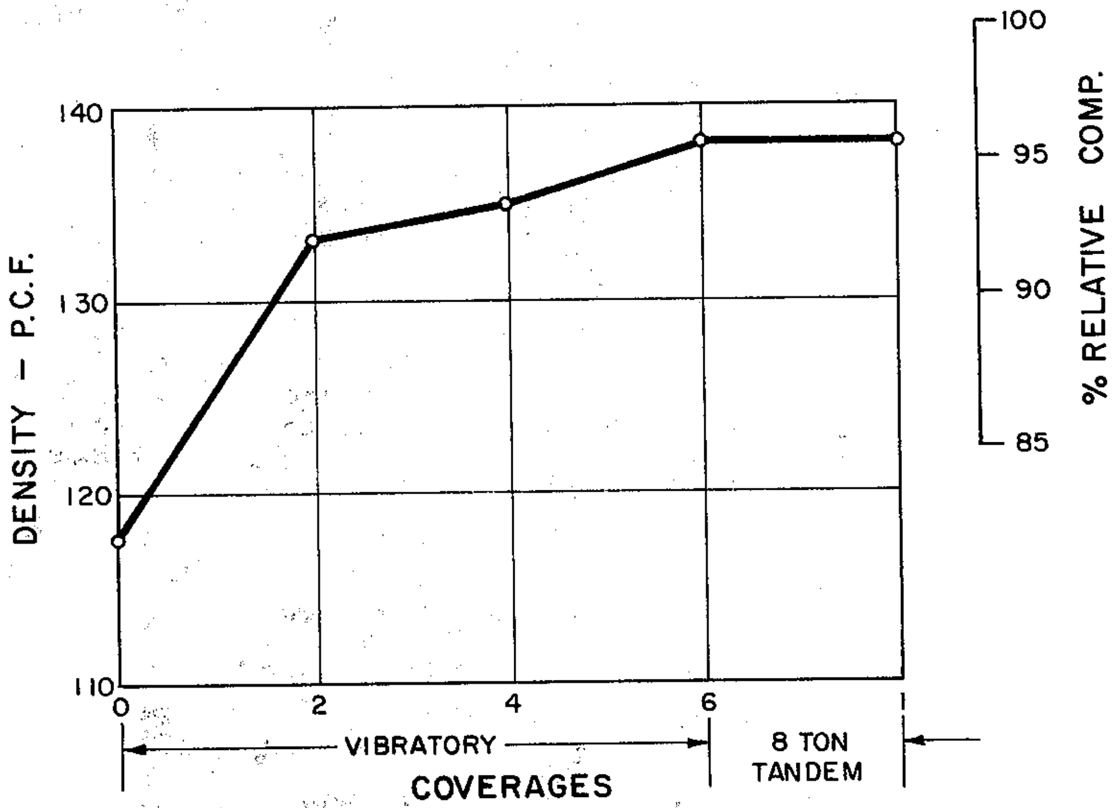


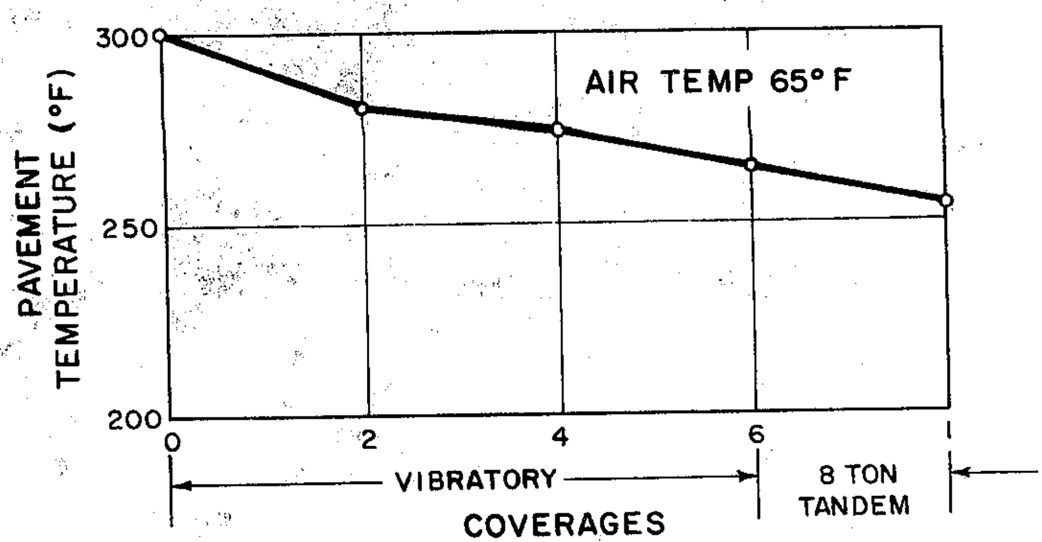
Figure 3 - Bomag B.W. 200

Figure 2

DENSITY GROWTH CURVE

ESSICK VR-54-RE





The weight of this double drum roller is 7.7 tons. The operation of this vibratory system is based on eccentric weights built upon each axle. These weights are simultaneously whirled in the same direction and 180° in phase opposition. The manufacturer claims that the horizontal forces of the two rotating weights are thus neutralized and the dynamic forces are effective only in a vertical direction. The diameter of each roller is 31.5" and the working width is 79". The overall length of the compactor is 6' 6".

For this study, the operating frequency was 2600 VPM with a amplitude of .030".

This roller was used on one experimental test section. The density growth curve is shown in Figure 4; as shown, the maximum density was obtained after 4 coverages. The 5th and 6th coverages show a slight reduction in the density. This decrease in density may have been due to the variance inherent in nuclear gauges.

Even though this roller's top speed is approximately 2 mph, it was able to keep up with the paver traveling at 40 feet per minute. However, the roller had to stop frequently for water as the two water tanks had a total capacity of only 72 gallons.

Although the vibrations for this compactor can be shut off, it cannot be used conveniently as a finishing roller due to the small gap between the adjacent drums on each axle (See Figure 3).

<u>Vibro-Plus-CC-50-A</u> (Figure 5)

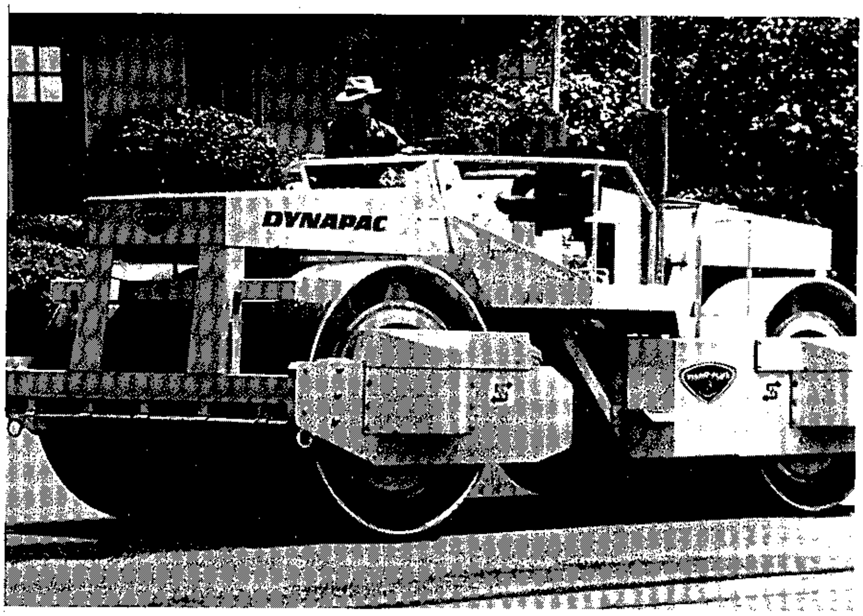
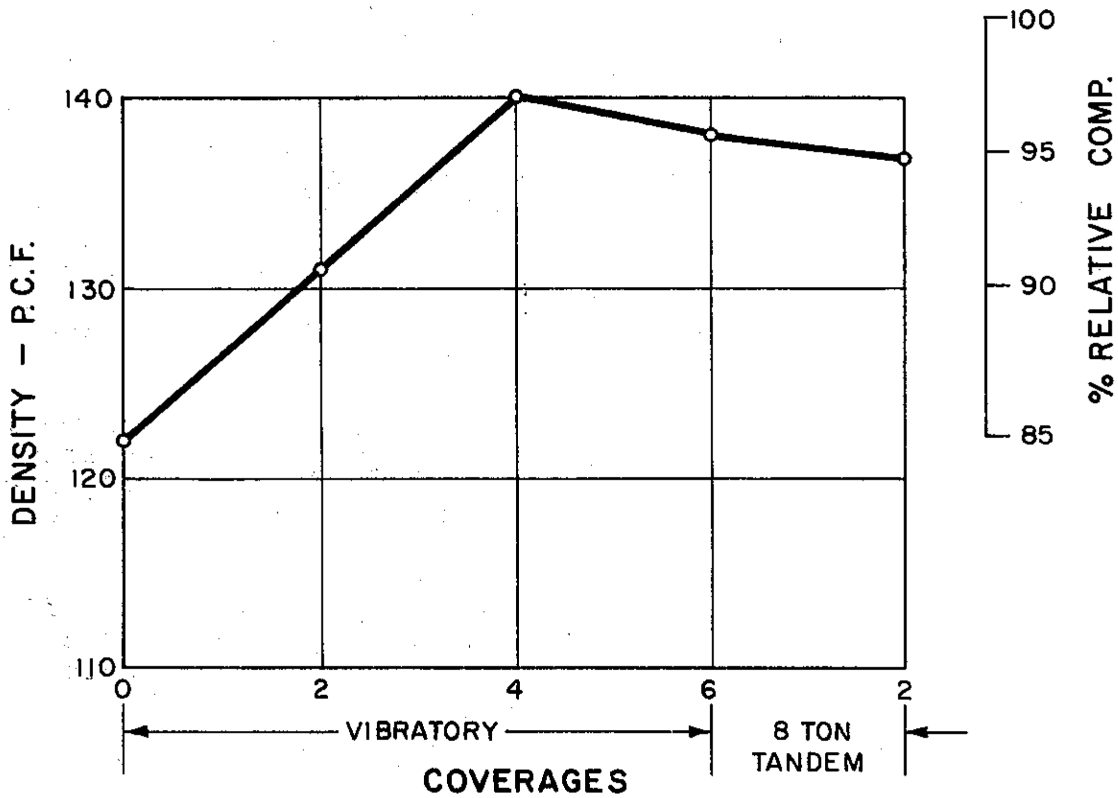


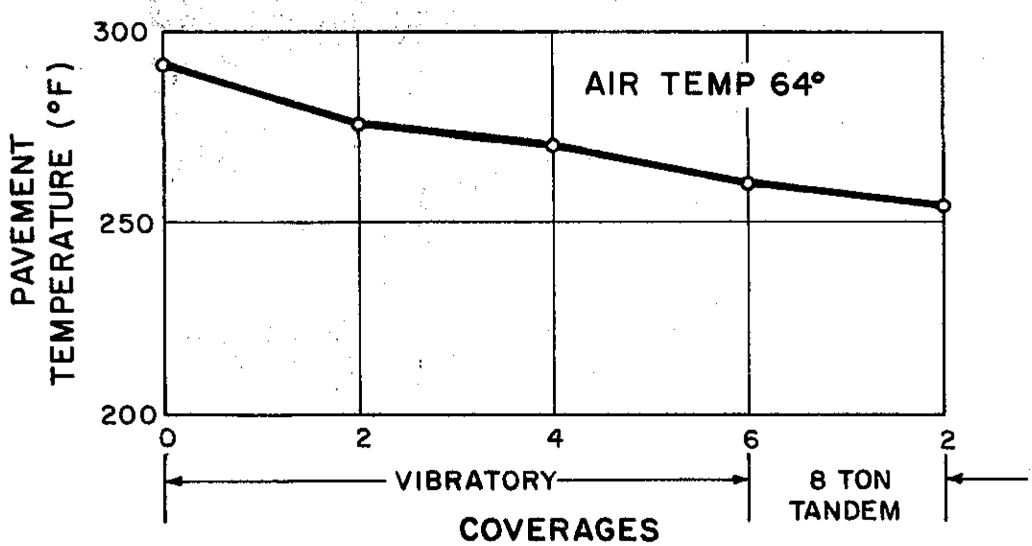
Figure 5 - Vibro-Plus CC-50-A

Figure 4

DENSITY GROWTH CURVE

BOMAG-BW200



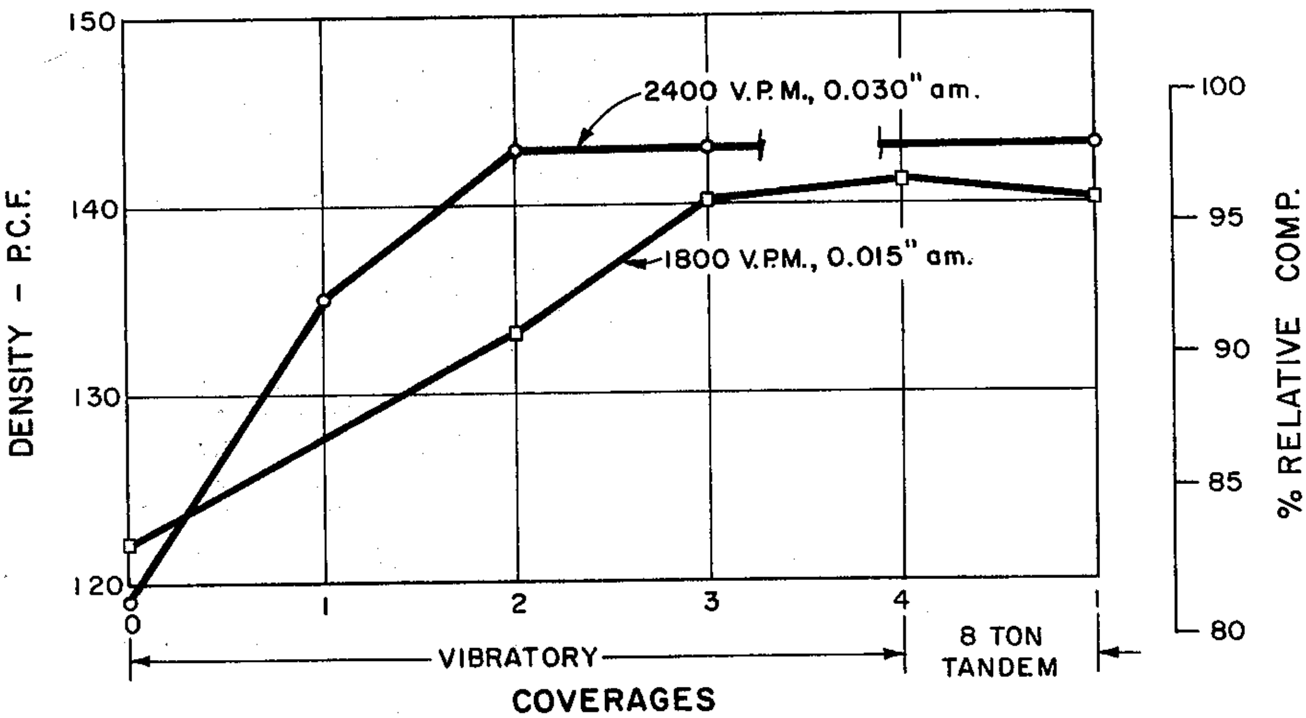


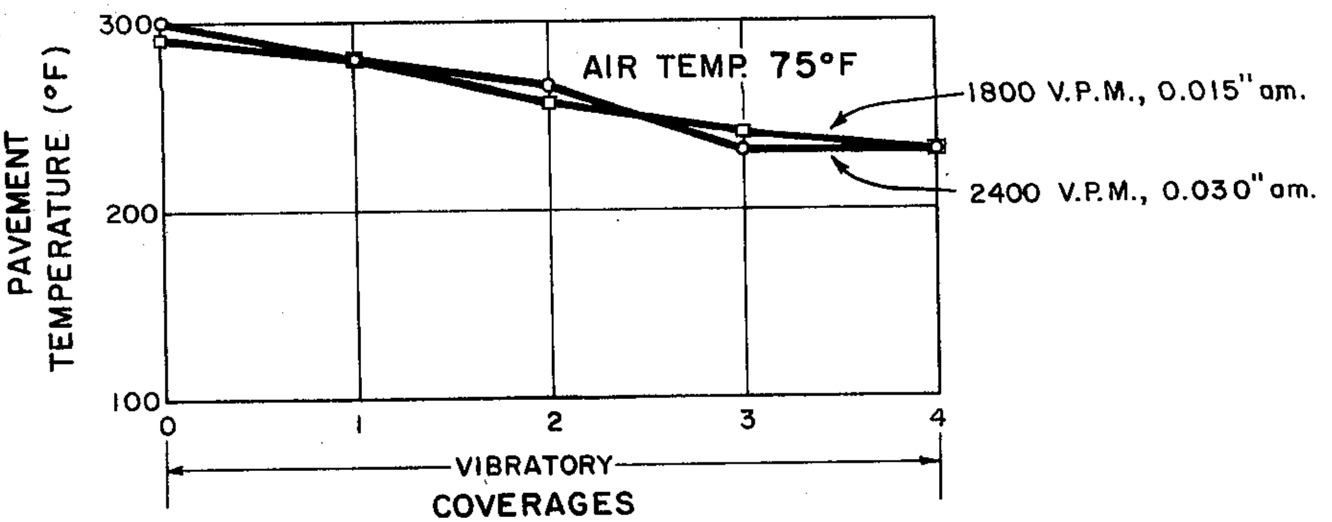
The weight of this double vibrating drum roller is 16 tons. A hydrostatic drive produces a frequency range of 1800 to 2400 VPM with independent control of each drum at the operator's console. This compactor can be used with either or both drums vibrating, or both drums static. When used with both drums vibrating, the frequency of each drum will be the same. Each drum is 60" in diameter and 84" in width. The overall length of this roller is 18' 6".

The CC-50-A was used on two experimental test sections, one in the Los Angeles area and the other in an area north of Sacramento. In both locations, a relative compaction greater than 95 percent was attained. As shown in Figure 6, when operating at a frequency of 2400 VPM and an amplitude of approximately 0.030", a maximum density of 143 P.C.F. (98 percent relative compaction) was reached after 2 coverages. Also shown in Figure 6 is the growth curve when using a lower amplitude and frequency. At these lower values 95 percent relative compaction was also obtained but an additional coverage of the roller was required. This roller can also be used as a finishing roller by simply turning off the vibrating unit. Minor problems were encountered with the water system; however, these were solved by changing to a different type of spray nozzle and adding a more efficient filtering system to the water tank.

Figure 6

DENSITY GROWTH CURVE
VIBRO-PLUS-CC-50-A





Tampo (RS-288-A) (Figure 7)

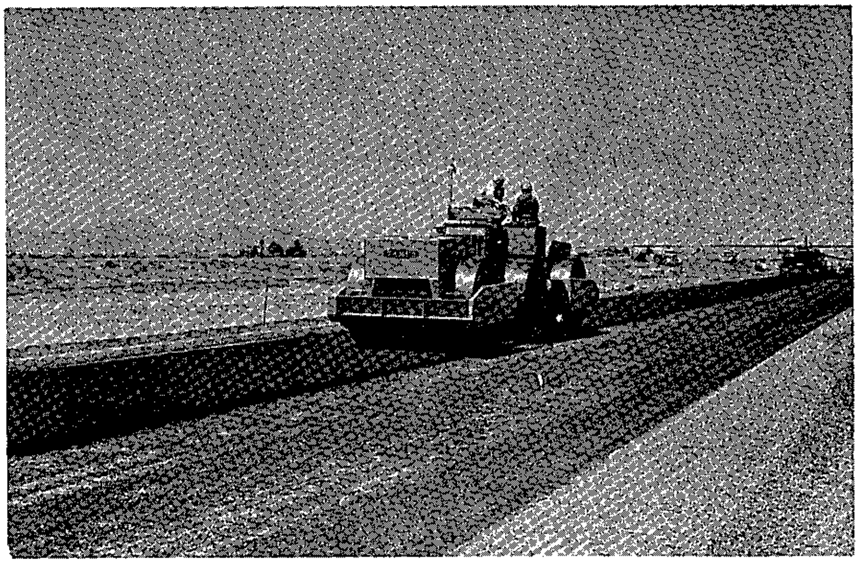


Figure 7 - Tampo RS-288-A

The weight of this double vibrating drum roller is 18.5 tons. A hydrostatic drive produces a frequency range from 1100 to 1750 VPM. This compactor can be used with either or both drums vibrating, or both drums static. When used with both drums vibrating, the frequency of each will be the same. The amplitude range is from about .020" to .065". The size of each drum is 60" in diameter and 84" in width, and the overall length of this roller is 26' 5".

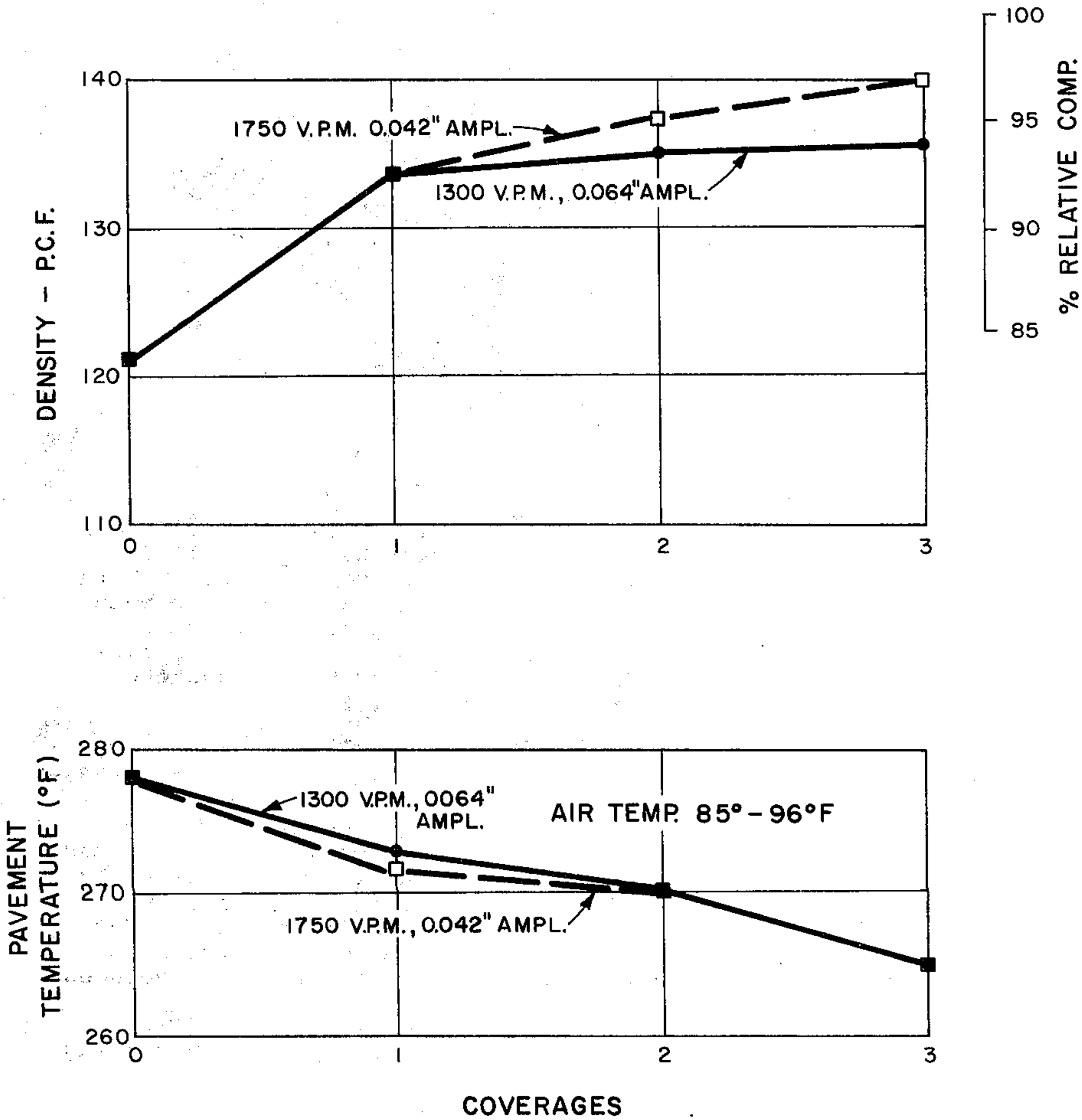
Figure 8 presents the pavement density and temperature results for one project. As shown in Figure 8, when the Tampo RS-288-A was operating at a frequency of 1300 VPM and an amplitude of .064" it failed to meet the density requirement of Method No. Calif. 913. The relative compaction could not be increased beyond 93 percent. This was achieved after two coverages and the third coverage showed no significant increase in density. However, when the frequency was increased to 1750 VPM with an amplitude of .042", a maximum density equal to 95 percent relative compaction was obtained after 2 coverages, and 97 percent after 3 coverages.

This roller can also be used as a finishing roller by turning off the vibrating system.

Figure 8

DENSITY GROWTH CURVE

TAMPO RS-288-A



Essick (VR-42-RE) (Figure 9)

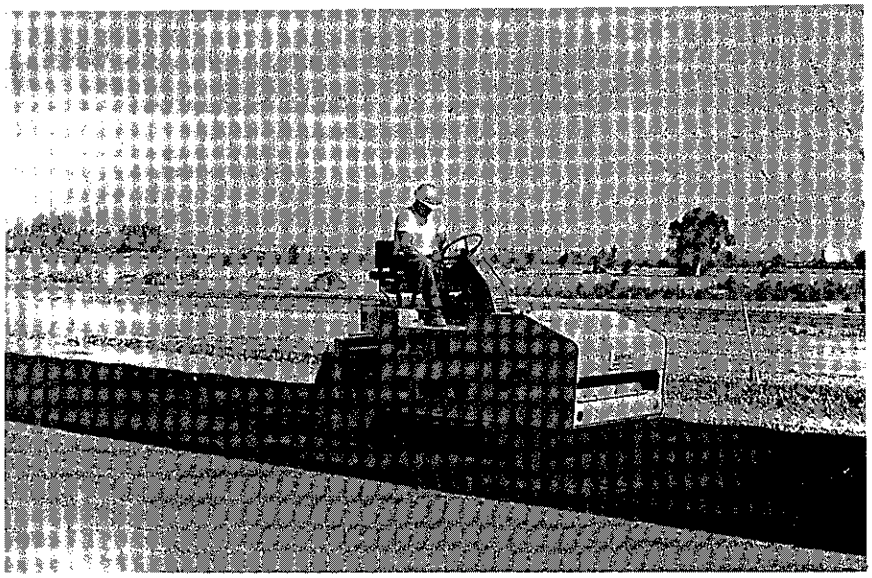


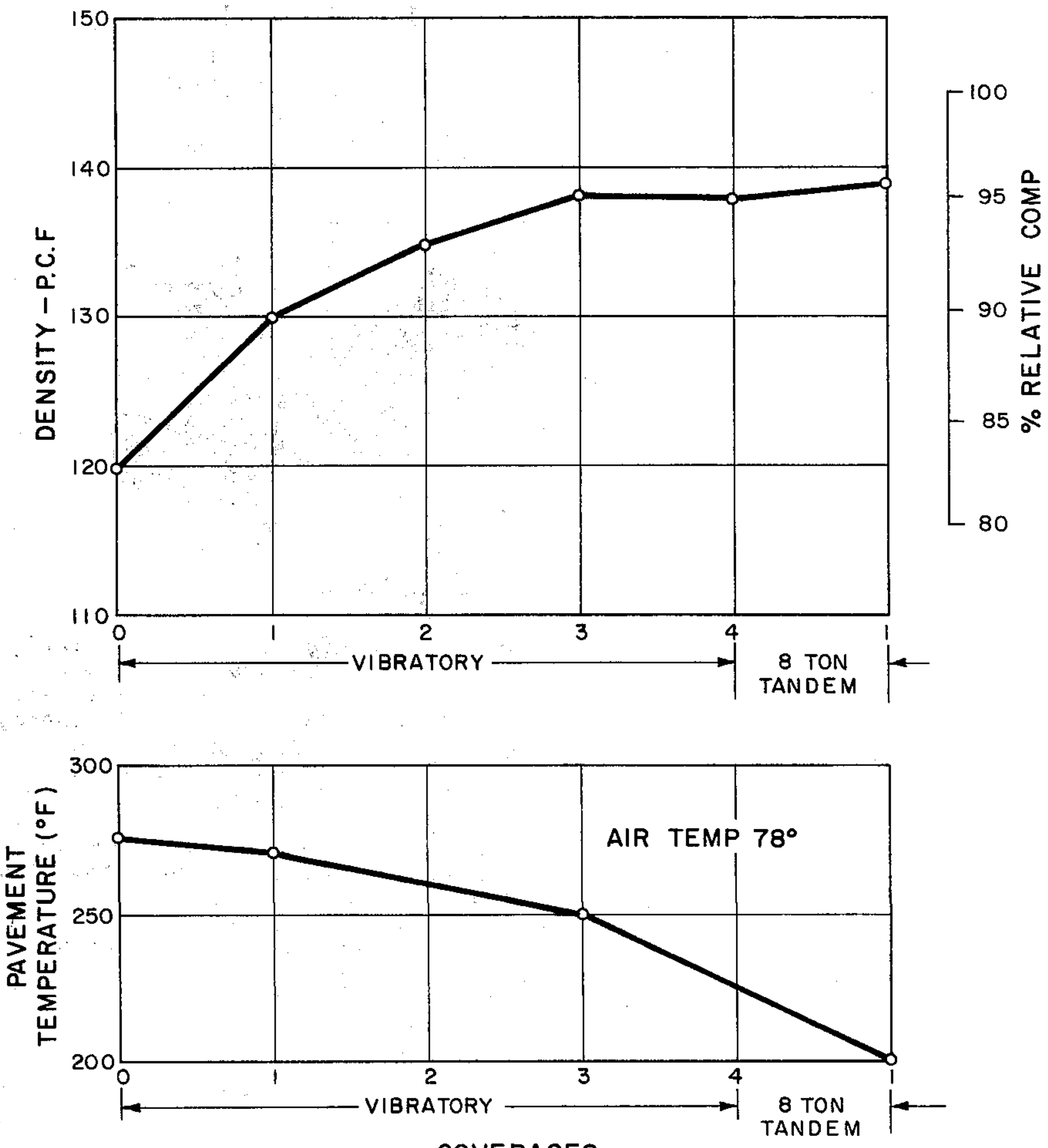
Figure 9 - Essick VR-42-RE

The manufacturer lists the weight of this compactor as 2.75 tons without ballast and 3.3 tons fully loaded. To date, this is the smallest vibratory roller that has been evaluated. An eccentric weight system produces vibrations at a frequency of 3600 VPM and an amplitude of .035 to .055 inches. The single vibrating drum is 30" in diameter and 42" in width. The overall length of the unit is 9' 2".

Although this compactor met the 95 percent relative compaction requirement (Figure 10), it is being limited to the compaction of shoulders for State projects because the 42 inch drum width necessitates an excessive number of passes for one coverage; consequently, this roller cannot keep up with a paver operating at a normal speed.

Figure 10

DENSITY GROWTH CURVE
ESSICK VR-42-RE



Summary

To date, we have tested nine other vibratory rollers, all of which have failed to meet the requirements set forth in Method No. Calif. 913. All nine rollers contained a single steel vibrating drum and steel or pneumatic drive wheels. Eight of the nine failed due to their inability to obtain 95 percent relative compaction. However, those using pneumatic drive wheels would have been rejected in any case due to pick-up by the rubber tires. One of the rollers of this type did achieve 95 percent relative compaction. However, it too was rejected due to undulations left in the pavement surface and pick-up by the rubber tires. Most of these rollers that failed compared favorably in weight (10-13 tons), frequency range (1100 to 2200) and amplitude with those rollers that were acceptable. However, the combinations of these characteristics on the failing rollers were such that satisfactory compaction and appearance of the asphalt concrete were not obtained. These failing rollers will be retested in the future if conditions warrant.

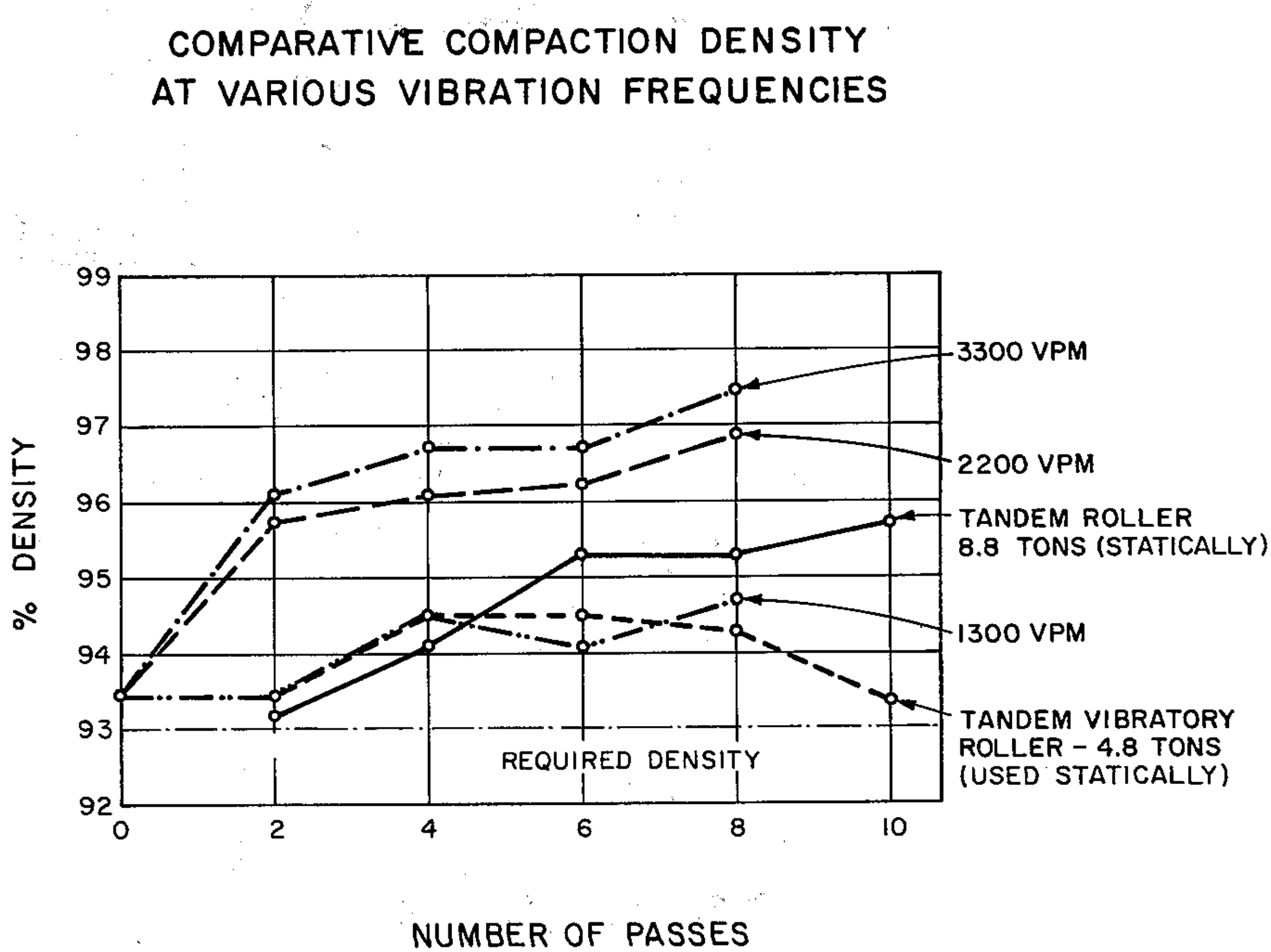
The vibratory compactors that have passed our qualification tests to date all have steel drums. It is also noted that those compactors using two vibrating drums can achieve 95 percent relative compaction with fewer coverages than the single vibrating drum rollers. In many instances the vibratory rollers can be operated as finish rollers, if so desired, by turning off the vibratory units. However, it may prove difficult to keep up with the paver when the roller is used for both breakdown and finish rolling.

DISCUSSION

There are many factors to consider when evaluating vibratory rollers. However, the three most important factors are the frequency, amplitude, and weight of the compactor. Frequency is defined as the number of cycles made by the vibrating unit in a given period of time, generally referred to as "vibrations per minute" (VPM). The nominal amplitude is defined as the distance travelled by the vibrating drum either side of its mean position when under the influence of the vibrator mechanism.

In a study presented by Mr. Fisher[2], his data (Figure 11) showed there was only a slight difference in density between a roller operating at 1300 VPM and the same roller operating statically. However, when the frequency of the same roller was increased to 2200, and then to 3300 VPM, (both with the same amplitude) the density was significantly increased. For the two rollers we tested in this manner, our findings

Figure 11



AFTER FISHER
LAYER THICKNESS-2"

agree with Fisher's in that use of higher frequencies and the same amplitude resulted in greater densities (See Figure 12). However, we have tested and failed rollers with frequencies as high as 2200 VPM, while a roller passed our qualification test with a frequency of 1750 VPM.

Some of the rollers using low frequencies (1100 to 1800 VPM) not only failed to meet our density requirements, but also left undulations on the surface of the pavement which, in itself, is sufficient reason for rejecting the roller. We have not observed undulations of this type with rollers operating at a frequency above 2000 VPM. Thus, frequency alone is not the governing factor with respect to adequate compaction of asphalt concrete.

We have also found that the vibratory rollers that use a high amplitude (more than .050") and low frequency (less than 1800 VPM) can leave small undulations, giving the pavement surface a "washboard" appearance. However, this unacceptable "washboard" appearance can be minimized by slowing down the speed of the roller to 1 or 2 miles/hr. and finishing all the rolling before the temperature of the pavement drops below 180°F. These undulations were not noticed when vibratory rollers operating at frequencies above 1800 VPM and amplitudes less than .040" were used. In the case of the Tampo RS-288-A, we did notice undulations; however, by operating with only the leading drum vibrating during the final breakdown coverage, all the undulations were ironed out.

One of the vibratory rollers we tested used a low frequency (1100 VPM) and a high amplitude (0.106"). It has been reported by others that the densities obtained with these rollers on soils were extremely high[3]. However, when using the same type of roller on asphalt concrete, we found the low frequency and high amplitude had a detrimental effect in that the top portion (top 1") of the pavement was not compacted adequately. Thus, combinations of frequency and amplitude that work well on soils will not necessarily work well on asphalt concrete.

At the beginning of this study, we assumed that the static weight of a vibratory roller was another important factor in attaining adequate compaction. We felt that a weight sufficient to maintain intimate contact between the pavement and the vibratory roller was required. We also assumed that a vibratory roller that weighed less than 4 tons would have a tendency to bounce. Since then we have found that our original assumptions were not entirely correct. We have found that the weight on the drum has considerable influence on compaction. However, this

Figure 12

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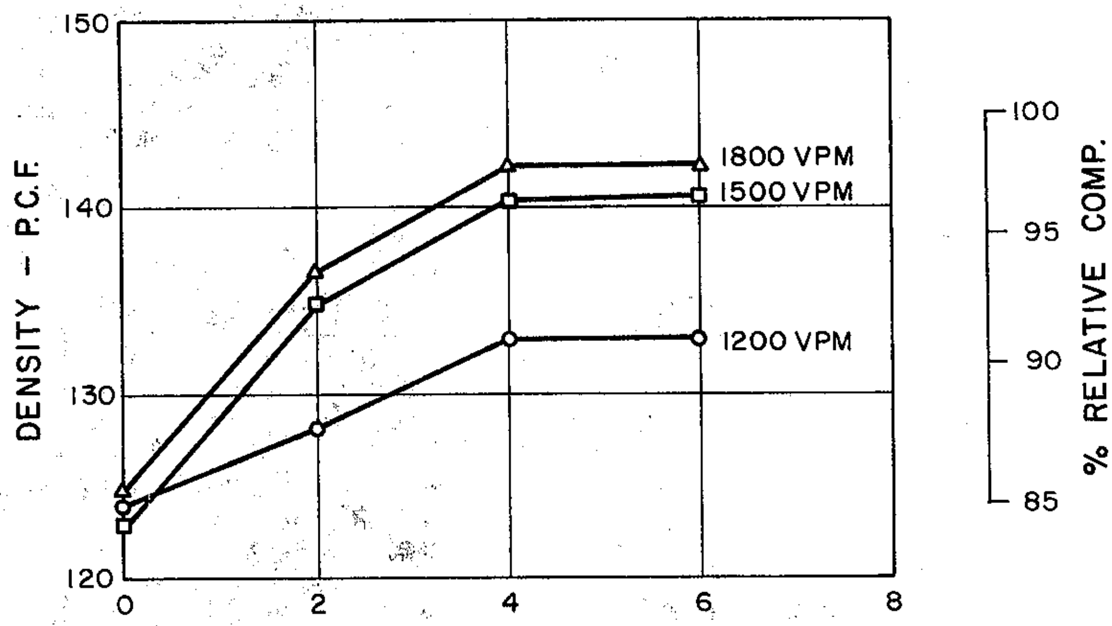
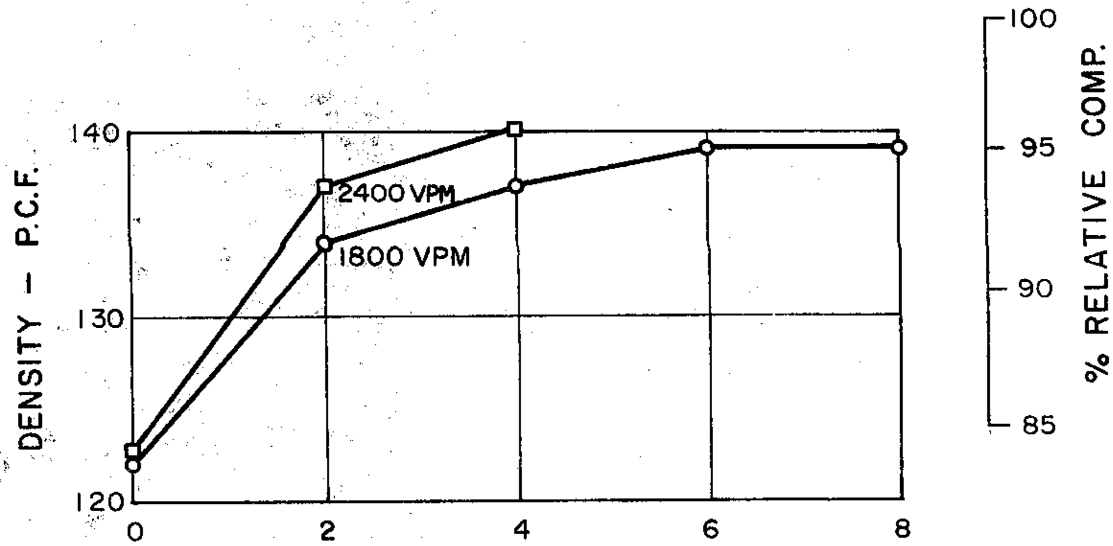


VIBRO PLUS CC-50-A



consists of the sprung and unsprung components of the weight. If this relation is out of balance with the vibratory characteristics of frequency and amplitude, then the performance of the vibratory roller is often erratic. However, if the sprung and unsprung weights of the roller are compatible with the frequency and amplitude being used, satisfactory compaction can be attained even with light rollers. For example, when the 3 ton Essick VR-42-RE described previously was used, there was no evidence of roller bounce or instability. This roller passed our qualification test and was able to achieve the required pavement densification with only one more coverage than was required with a vibratory roller weighing 16 tons.

Information gained from this study clearly shows there is no set frequency, nominal amplitude, or roller weight that must be used to attain adequate pavement densification. There is, however, a relationship between all these variables, and these variables must complement each other if a roller is to provide satisfactory compaction.

VIBRATORY VS. STATIC STEEL AND PNEUMATIC COMPACTION

To study the relative effect of vibratory rollers on density, permeability, and asphalt and/or fine aggregate migration to the surface, a comparison was made between steel static, pneumatic static, and vibratory compacted sections on one of the test projects.

The asphalt concrete used in this test section was a California Type "A" mix which is essentially an all-crushed aggregate. An 85-100 penetration asphalt was used and the compacted thicknesses of the test sections were 0.33' for the base course and 0.17' for the finish course for a total of 0.50'.

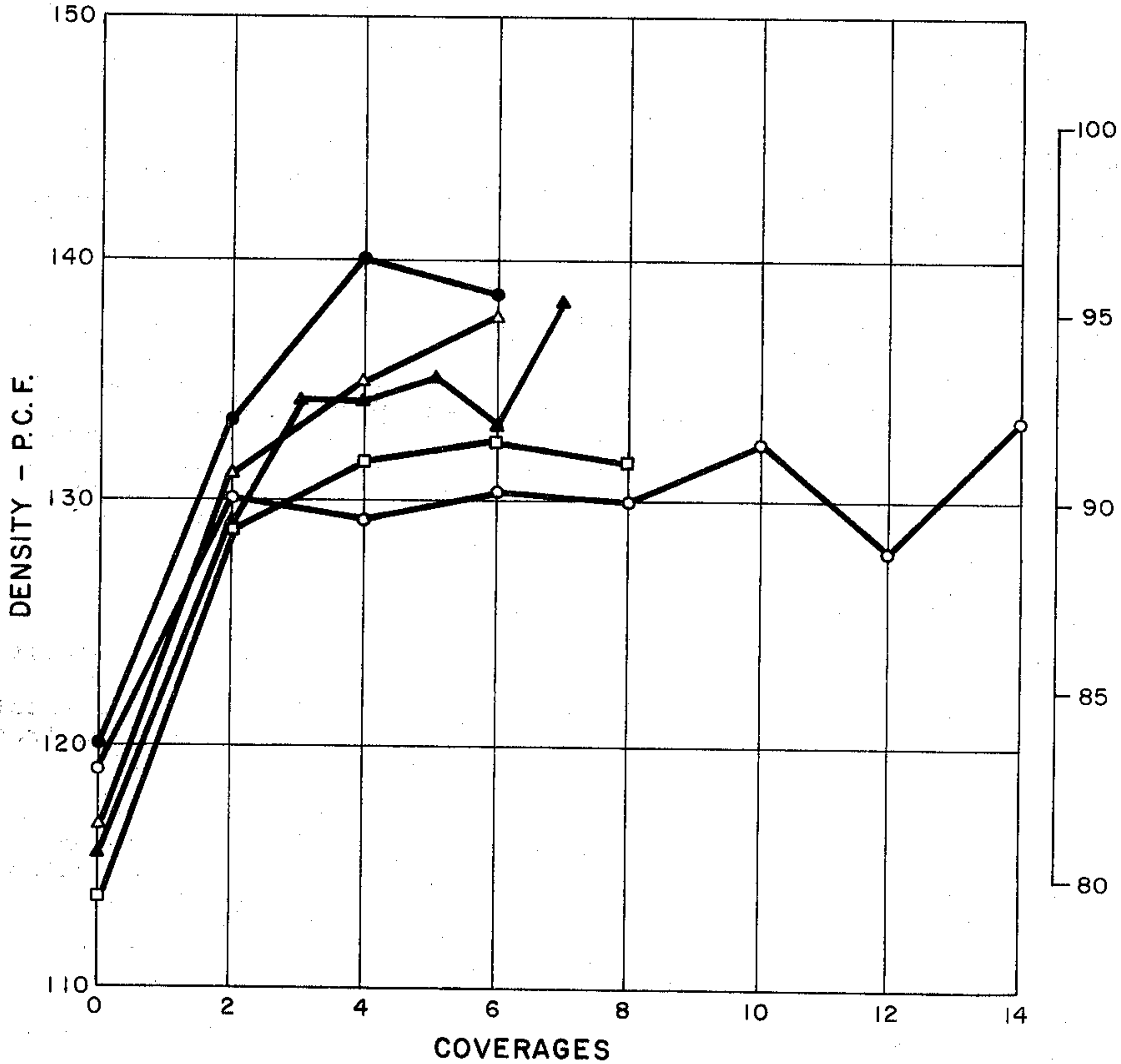
Sections of pavement compacted using each of three vibratory rollers and using a pneumatic roller for breakdown rolling were compared with a section rolled using the California standard rolling procedure. This standard procedure consisted of breakdown rolling with a 12-ton steel tandem (3 coverages), sealing with a pneumatic (3 coverages), and finishing with an 8-ton tandem (minimum of 1 coverage). For the test sections compacted using only a pneumatic breakdown roller, a 16.7 ton Bros was used until maximum compaction was achieved and then an 8 ton tandem was used for finishing. The three vibratory rollers included: vibratory roller A, with a 7.7 ton double vibratory drum roller manufactured by Bomag (BW-200) (See Figure 3); vibratory roller B, a 6-8 ton steel tandem roller manufactured by Essick (VR-54-RE) (See Figure 1); and vibratory roller C, a 9 ton pneumatic drive roller manufactured by Ray-Go (404-A). The Ray-Go weighs 9.3 tons and contains an 84" wide drum. Its operating frequency ranges from 1150 to 1500 VPM. The manufacturer did not specify the operating amplitude.

Density Comparison

The pavement compacted using the normal rolling procedure had an average of 95 percent relative compaction after the seven coverages with the three rollers. The pneumatic roller produced an average relative compaction of 92 percent after 14 coverages. The three test sections compacted using vibratory roller A had an average relative compaction of 97 percent after 4 coverages. The three sections compacted using vibratory roller B had an average relative compaction of 96 percent after 6 coverages. Use of vibratory roller C produced an average relative compaction of 92 percent after 8 coverages. Thus, neither the pneumatic roller or vibratory roller C complied with the compaction requirements of Method No. Calif. 913. A relative compaction comparison is shown in Figure 13.

Figure 13

COMPARATIVE RELATIVE COMPACTION CURVES



● - 7 TON DOUBLE VIBRATORY ROLLER (BOMAG) - ROLLER A
△ - 6-8 TON TANDEM VIBRATORY ROLLER (ESSICK) - ROLLER B
▲ - NORMAL ROLLING PROCEDURE
○ - 16.7 TON PNEUMATIC (BROS.)
□ - 9 TON VIBRATORY ROLLER/PNEU. DRIVE (RAY-GO) - ROLLER C

Water Permeability

It is well-known that dense impermeable asphalt concrete provides a more durable pavement. Consequently, the effect of these various compaction procedures on permeability was also measured. Immediately after construction, all the pavement appeared to have the same surface texture with the exception of the pavement compacted with vibratory roller A. The surface texture of this area appeared to be extremely tight. The water permeability test results (Test Method No. Calif. 341) confirmed this opinion (See Table 1). In fact, all the sections compacted with vibratory rollers on this job (Project 1, Table 1) had water permeability results lower than those compacted using the normal (static) and pneumatic compaction equipment.

Permeability tests were also performed on other projects to verify these findings. These are designated as projects 2, 3, and 4 in Table 1. A fourth vibratory roller, manufactured by Vibro-Plus (See Figure 5), was used on project number 4 (vibratory roller D). In all cases, pavements compacted using the vibratory rollers had lower permeabilities than pavements compacted using the other types and combinations of rollers. It should be noted, however, that different materials from different projects gave widely different permeabilities.

Migration of Asphalt and/or Asphalt Coated Fines

Flushing or bleeding pavements are caused by a migration of asphalt and/or asphalt coated fines to the surface of the pavement. To determine if there had been a migration of this type to the pavement surface due to the effects of vibration, three cores were taken from each section of project 1. The cores taken from the pavement compacted with vibratory roller C were damaged and could not be used for testing. The cores from the other test sections were sliced as shown in Figure 14; that is, the top 1.5" of the cores were sliced into three 0.5" sections. The asphalt from each section was extracted and then the aggregate gradation determined. A comparison is presented in Table 2. As shown, the top 0.5" in the 97 percent compacted vibratory section (vibratory roller A) contained 1.2 percent more asphalt than the upper 0.5 inches of the core compacted using the normal static rolling procedure. Also the top 0.5" from the pavement compacted with vibratory roller A had a finer gradation than the top 0.5" of all cores obtained from the other compaction test sections.

It is also interesting to note that the average asphalt content for the top 1.5" of the pavement compacted with vibratory roller A is 0.5 percent higher than the asphalt content of the cores taken

Figure 14

SLICED SECTIONS OF A.C. CORES

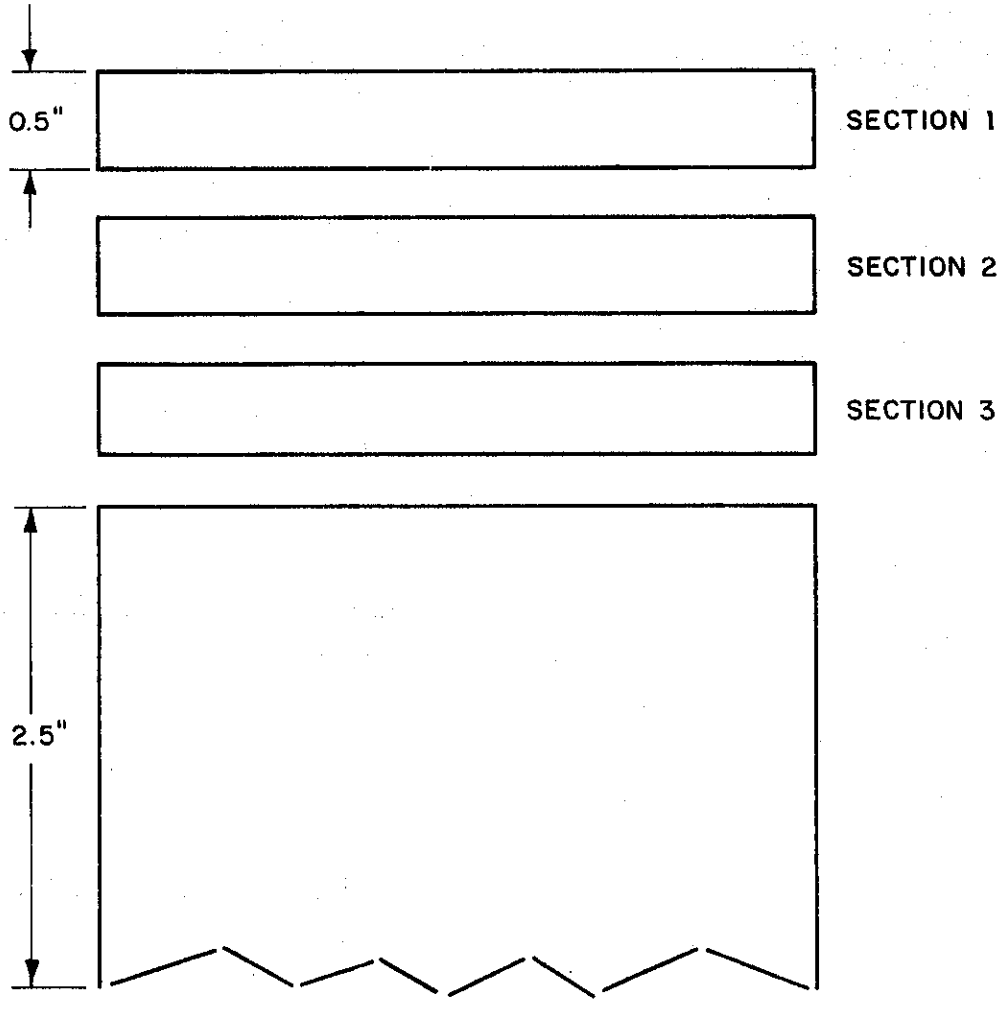


TABLE 1

COMPARATIVE PERMEABILITY TESTS

Project 1

Roller Type	Average Permeability (Ml/Min.)
1. Vibratory A - BOMAG	54
2. " B - ESSICK	409
3. " C - RAY-GO	533
4. Bros Pneumatic (16.7 Ton)	590
5. Normal Rolling Procedure	590

Project 2

Roller Type	Average Permeability (Ml/Min.)
1. Vibratory B - ESSICK	174
2. " C - RAY-GO	244
3. Michigan Pneumatic "Air-on-the-Run" (16 Ton)	294
4. Normal Rolling Procedure	305
5. No. 4 w/extra rolling during breakdown	247

Project 3

Roller Type	Average Permeability (Ml/Min.)
1. Vibratory C - RAY-GO	117
2. Normal Rolling Procedure	328
3. No. 2 w/extra rolling during breakdown	183

Project 4

Roller Type	Average Permeability (Ml/Min.)
1. Vibratory D - VIBRO-PLUS	433
2. "	425
3. "	391
4. Normal Rolling Procedure	520
5. "	634
6. "	569

TABLE 2

	Bomag Vibratory A			Essick Vibratory B			16.7 Ton Bros. Pneumatic			Normal Static Rolling Procedure		
Final Density	97%			96%			92%			95%		
Section of 1.5" Core	1	2	3	1	2	3	1	2	3	1	2	3
Asphalt Content	5.2%	4.7%	4.2%	4.6%	4.5%	4.3%	3.7%	4.3%	4.8%	4.0%	3.8%	4.8%
Grading of Aggregate (Percent Passing)												
3/4"	100	100	100	100	100	100	100	100	100	100	100	100
1/2"	97	88	92	95	91	88	82	85	93	79	81	90
3/8"	80	68	78	86	78	79	66	74	82	61	69	80
#4	60	55	59	63	60	63	51	58	62	47	53	60
#8	40	36	39	39	37	40	33	37	41	32	35	41
#16	28	25	25	25	24	25	22	24	27	22	24	26
#30	18	16	16	17	16	15	14	16	17	15	15	17
#50	12	10	11	11	10	10	9	11	11	10	10	11
#100	9	7	7	10	7	7	7	8	10	7	7	7
#200	6	4	5	5	5	5	4	5	5	5	4	5

from pavement compacted using the normal and pneumatic procedures. However, the average asphalt content is only 0.2 percent higher than the other vibratory-rolled section, indicating that some asphalt was being vibrated to the surface.

Results from the pneumatically rolled sections are very similar to the normal static rolled sections, indicating the procedure used in the normal static and pneumatic rolled sections did not significantly affect the gradation or migration of the fines and asphalt.

It is obvious that vibratory rollers do effect the migration of asphalt and/or asphalt coated fines to the surface of the pavement. However, visual inspection of all test sections compacted by vibratory rollers showed no signs of asphalt flushing, and none of the test sections could be considered hazardous up to three years after construction.

REFERENCES

1. Zube, E., Skog, J., and Cechetini, J., "Compaction of Thick-Lift Asphalt Concrete Pavement," December 1968, Interim Report.

2. Fisher, F., "The Technical Aspects of Compaction in Earth-moving and Road Construction", Clark Equipment Company.

3. Tope, A. R., "Technical Aspects of Vibrating Rollers in Relation to Performances", Australian Road Research, December, 1967.

State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

Method No. Calif. 913-B
April 2, 1973
(3 pages)

METHOD FOR EVALUATING THE COMPACTION CAPABILITIES OF ASPHALT CONCRETE COMPACTORS

A. Equipment Qualification

All new compaction equipment, and other compaction equipment as designated, must meet a given relative compaction requirement. Relative compaction is defined as the ratio of the in-place density of the asphalt concrete pavement to the test maximum density (average of 5 specimens) of the same asphalt concrete mix when compacted by the California kneading compactor, Test Method No. Calif. 304.

B. Determining Maximum Density of Test Sections

1. The test section constructed for the purpose of evaluating a given compactor shall be one lane wide, 300 feet in length and marked in 100 foot increments.

2. Prior to testing, the contractor or manufacturer's representative shall specify the operating conditions of the compactor being tested. If a vibratory roller is being tested, these conditions shall include frequency and amplitude. Tire pressure shall be included in the specified operating conditions of a pneumatic roller. Qualification compaction tests can be made on any Type A or Type B asphalt concrete mix. However, if the roller has previously been qualified on a Type B mix with a ¾″ maximum aggregate, either coarse or medium grading, additional qualification can be waived at the discretion of the engineer.

3. The temperature of the asphalt concrete mix at mid-depth shall be between 270–280°F at the beginning of the breakdown rolling. The compacted thickness limits shall be between 0.20 to 0.30 of a foot. Rolling of the test section shall continue until:

a. 95 percent relative compaction is obtained, or

b. No appreciable increase in density is obtained by additional rolling.

4. When the compactor being tested has met the above requirements, a final coverage shall be made by an 8-ton tandem (steel) roller, or by a compactor that exerts pressure equivalent to the pressure (lbs. per lin. inch) exerted by an 8-ton tandem (steel) roller.

5. Within each 100 foot increment of the 300 foot test section, take ten (10) one minute readings with a nuclear density gage. Select the location of each test by a statistical method such as the nonbiased sample cards, or random numbers.

6. For the acceptance of a specific compactor, the mean density for the ten locations of each 100 foot test section shall be a minimum of 95% relative compaction, and none of the individual tests shall be below 92% relative compaction. Other reasons for nonacceptance will include ridges, indentations or other objectionable marks in the asphalt concrete after final rolling has been completed.

7. Record acceptable operating conditions for approved equipment on Form HMR T-3133 as shown in Fig. I.

REFERENCE

Test Method No. Calif. 304

End of Text on Calif. 913-B

CALCULATION EXAMPLE

Sta Density	Passed Test Section Table 1: 368+50 to 369+50 (lbs/ft³)	Passed Test Section Table 1: 369+50 to 370+50 (lbs/ft³)	Passed Test Section Table 1: 370+50 to 371+50 (lbs/ft³)	Failed Test Section Table 2: 117+25 to 118+25 (lbs/ft³)	Failed Test Section Table 2: 118+25 to 119+25 (lbs/ft³)	Failed Test Section Table 2: 119+25 to 120+25 (lbs/ft³)
1	138	138	140	137	138	136
2	139	139	138	138	137	138
3	138	138	137	136	136	137
4	137	136	140	137	139	140
5	138	138	138	136	137	138
6	140	139	139	138	136	*133
7	138	137	141	139	138	136
8	138	140	138	137	135	*133
9	139	136	139	135	136	139
10	137	138	138	136	134	138
Average	138.2	137.8	138.8	136.9	136.6	136.8
Relative Compaction	95.3%	95.1%	95.7%	95.1%	*94.9%	95.0%

Table 1: Based on Density of Compacted Specimens of 145 lbs/ft³

Table 2: Based on Density of Compacted Specimens of 144 lbs/ft³

*Any one of these values would have failed the roller for State work.

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS & RESEARCH DEPARTMENT

REPORT OF TESTS ON

District	County	Route	P.M.	Date Tested
Contractor			Manufacturer	
Model #	Weight	Freq. Range	Ampl.	
ACCEPTED OPERATING CONDITIONS	Freq.	Amp.	Max. Speed	No. of Coverages
SPECIFICATIONS				
REMARKS				

DATE TESTED:	
TESTED BY:	
APPROVED BY:	

HMR T- (11-71)

FIGURE 1

APPENDIX B

39.02
1-2-73

ASPHALT CONCRETE.--Asphalt concrete shall be

____
and shall conform to the provisions in Section 39, "Asphalt Concrete," of the Standard Specifications and these special provisions.

The aggregate shall conform to the ______________________________

____
grading specified in Section 39-2.02, "Aggregate," of the Standard Specifications.

The first, fourth and fifth paragraphs in Section 39-6.01, "General Requirements," of the Standard Specifications are amended to read:

> All mixtures, except open-graded, shall be spread and compacted at such a temperature that all initial or break-down compaction shall be performed when the temperature of the mixture is not less than 250°F., except that for layers where the compacted thickness will exceed 0.25-foot, the Engineer may direct that compaction be performed at a lower temperature. Open-graded mixture shall be spread at a temperature of not less than 200°F. and not more than 250° F., unless a higher temperature is directed by the Engineer.
>
> Asphalt concrete and asphalt concrete base shall be spread and compacted in layers. The top layer of asphalt concrete shall not exceed 0.20-foot in compacted thickness. The next lower layer shall not exceed 0.25-foot in compacted thickness, and any lower layers shall not exceed 0.40-foot in compacted thickness. Each layer of asphalt concrete base shall not exceed 0.40-foot in compacted thickness. No layer shall be placed over a layer which exceeds 0.25-foot in compacted thickness until the temperature at mid depth, of the layer which exceeds 0.25-foot in compacted thickness, is not more than 160° F.
>
> Asphalt concrete and asphalt concrete base to be placed on shoulders and other areas off the traveled way having a width of 8 feet or more, shall be spread in the same manner as specified above. When the shoulders and other areas are less than 8 feet in width the material may be

deposited and spread in one or more layers by any mechanical means that will produce a uniform smoothness and texture. Unless otherwise shown on the plans, asphalt mixtures shall not be handled, spread, windrowed or stored in such a manner that will stain the finished surface of any pavement or other improvements.

A pass shall be one movement of a roller in either direction. A coverage shall be as many passes as are necessary to cover the entire width being paved. Overlap between passes during any coverage, made to insure compaction without displacement of material in accordance with good rolling practice, shall be considered to be part of the coverage being made and not part of a subsequent coverage. Each coverage shall be completed before subsequent coverages are started.

The first, second, third, fourth, fifth and twelfth paragraphs in Section 39-6.03, "Compacting," of the Standard Specifications are amended to read:

> Initial or breakdown compaction shall consist of 3 coverages of a layer of asphalt mixture and shall be performed with a 2-axle or 3-axle tandem or a 3-wheel roller weighing not less than 12 tons except that other compacting equipment may be used for the initial or breakdown compaction if it has been approved by the Engineer in accordance with Method No. Calif. 913 and if it is operated according to the procedures designated in the approval. Such approval will contain the minimum number of coverages required for the specific construction equipment.
>
> Rollers, excepting approved vibratory rollers, shall conform to the provisions in Section 39-5.02, "Rolling Equipment," of the Standard Specifications. All rollers shall be equipped with pads and a watering system for the roller wheels which prevent sticking of asphalt mixtures to the pneumatic or steel tired wheels. A parting agent, which will not damage the asphalt mixture, as determined by the Engineer, may be used to aid in preventing sticking of the mixture to the wheels.
>
> Rolling shall commence at the lower edge and shall progress toward the highest portion, except that when compacting layers which exceed 0.25-foot in compacted thickness, and if directed by the Engineer, rolling shall commence at the center and shall progress outwards.

Except when approved vibratory rollers are used for initial compaction, the initial or breakdown compaction shall be followed immediately by additional rolling consisting of 3 coverages with a pneumatic-tired roller. Coverages with a pneumatic-tired roller shall start when the temperature of the mixture is as high as practicable, preferably above 180° F., and shall be completed while the temperature of the mixture is at or above 150° F. Additional compaction with pneumatic-tired rollers will not be required when approved vibratory rollers are used for the initial or breakdown compaction.

Excepting Open Graded asphalt concrete, each layer of asphalt concrete and asphalt concrete base shall be additionally compacted, without delay, by a final rolling consisting of not less than one coverage with a 2-axle tandem roller weighing not less than 8 tons.

During rolling operations, and when ordered by the Engineer, the asphalt concrete shall be cooled by applying water. No layer shall be cooled with water unless ordered or permitted by the Engineer. The water ordered by the Engineer will be paid for as extra work as provided in Section 4-1.03D of the Standard Specifications.